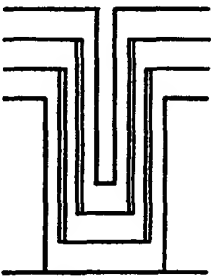
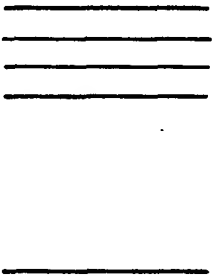
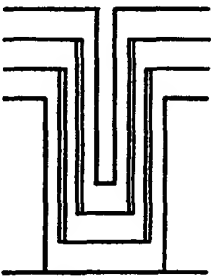
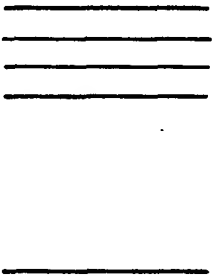
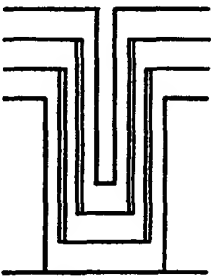
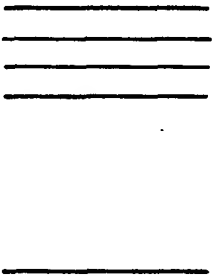


PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification <sup>5</sup> : <b>H01L 23/485</b></p>	<p><b>A1</b></p>	<p>(11) International Publication Number: <b>WO 92/20099</b></p> <p>(43) International Publication Date: 12 November 1992 (12.11.92)</p>						
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; vertical-align: top; padding: 5px;"> <p>(21) International Application Number: PCT/CA92/00185</p> <p>(22) International Filing Date: 1 May 1992 (01.05.92)</p> <p>(30) Priority data: 2,041,730                      2 May 1991 (02.05.91)                      CA</p> <p>(71) Applicant (for all designated States except US): MITEL CORPORATION [CA/CA]; 350 Legget Drive, P.O. Box 13089, Kanata, Ontario K2K 1X3 (CA).</p> <p>(72) Inventor; and (75) Inventor/Applicant (for US only) : OUELLET, Luc [CA/CA]; 711 Caron, Granby, Quebec J2J 1M7 (CA).</p> <p>(74) Agent: MITCHELL, Richard, J.; Marks &amp; Clerk, 55 Metcalfe Street, Suite 1380, P.O. Box 957, Station B, Ottawa, Ontario K1P 5S7 (CA).</p> </td> <td style="width: 50%; vertical-align: top; padding: 5px;"> <p>(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE, DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB, GB (European patent), GR (European patent), IT (European patent), JP, KR, LU (European patent), MC (European patent), NL (European patent), SE (European patent), US.</p> <p><b>Published</b> <i>With international search report.</i></p> </td> </tr> </table>			<p>(21) International Application Number: PCT/CA92/00185</p> <p>(22) International Filing Date: 1 May 1992 (01.05.92)</p> <p>(30) Priority data: 2,041,730                      2 May 1991 (02.05.91)                      CA</p> <p>(71) Applicant (for all designated States except US): MITEL CORPORATION [CA/CA]; 350 Legget Drive, P.O. Box 13089, Kanata, Ontario K2K 1X3 (CA).</p> <p>(72) Inventor; and (75) Inventor/Applicant (for US only) : OUELLET, Luc [CA/CA]; 711 Caron, Granby, Quebec J2J 1M7 (CA).</p> <p>(74) Agent: MITCHELL, Richard, J.; Marks &amp; Clerk, 55 Metcalfe Street, Suite 1380, P.O. Box 957, Station B, Ottawa, Ontario K1P 5S7 (CA).</p>	<p>(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE, DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB, GB (European patent), GR (European patent), IT (European patent), JP, KR, LU (European patent), MC (European patent), NL (European patent), SE (European patent), US.</p> <p><b>Published</b> <i>With international search report.</i></p>				
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<p>(54) Title: STABILIZATION OF THE INTERFACE BETWEEN ALUMINUM AND TITANIUM NITRIDE</p>								
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th colspan="2" style="padding: 5px;">BEFORE AND AFTER HEAT TREATMENT</th> </tr> <tr> <th style="width: 50%; padding: 5px;">PATTERNED</th> <th style="width: 50%; padding: 5px;">UN-PATTERNED</th> </tr> <tr> <td style="padding: 10px; vertical-align: top;">  <div style="margin-left: 20px;"> <p>1000 nm Al over 120 nm TiN over 100 nm Poly over 700 nm PSG over Monosilicon</p> <p><b>Silicon</b></p> </div> </td> <td style="padding: 10px; vertical-align: top;">  <div style="margin-left: 20px;"> <p>200 nm Al over 120 nm TiN over 1000 nm Poly over 400 nm SG over Monosilicon</p> <p><b>Silicon</b></p> </div> </td> </tr> </table>			BEFORE AND AFTER HEAT TREATMENT		PATTERNED	UN-PATTERNED	 <div style="margin-left: 20px;"> <p>1000 nm Al over 120 nm TiN over 100 nm Poly over 700 nm PSG over Monosilicon</p> <p><b>Silicon</b></p> </div>	 <div style="margin-left: 20px;"> <p>200 nm Al over 120 nm TiN over 1000 nm Poly over 400 nm SG over Monosilicon</p> <p><b>Silicon</b></p> </div>
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<p>(57) Abstract</p> <p>A semiconductor device comprises at least one metal interconnect layer, a titanium-based barrier layer in contact with the metal interconnect layer. The metal interconnect layer contains titanium in an amount up to the limit of solid solubility at the peritectic temperature. The arrangement is effective to reduce hillock, spike, and notch formation in the semiconductor device.</p>								

## INTERNATIONAL SEARCH REPORT

PCT/CA 92/00185

International Application No

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC		
Int.Cl. 5 H01L23/485		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
Int.Cl. 5	H01L	
Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>		
Category *	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
X	PATENT ABSTRACTS OF JAPAN vol. 12, no. 385 (E-668)14 October 1988 & JP,A,63 129 662 ( FUJITSU LTD ) 2 June 1988 see abstract ---	1, 14
A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 150 (E-408)31 May 1986 & JP,A,61 008 971 ( NIPPON GAKKI SEIKO KK ) 16 January 1986 see abstract ---	1, 8, 14
A	EP,A,0 304 728 (SIEMENS AG) 1 March 1989 see column 1, line 37 - line 48; claim 1 ---	1, 8, 14
P,A	EP,A,0 430 403 (SGS-THOMSON MICROELECTRONICS, INC ) 5 June 1991 see column 3, line 45 - column 4, line 32 --- -/-	1, 14
<p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"A" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
20 JULY 1992	29. 07. 92	
International Searching Authority	Signature of Authorized Officer	
EUR PEAN PATENT OFFICE	GREENE S.K. <i>SK Greene</i>	

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	US,A,4 999 160 (LOWREY ET AL) 12 March 1991 see column 3, line 11 - line 36 ---	1,14
A	US,A,4 107 726 (SCHILLING) 15 August 1978 see column 1, line 31 - line 62; figure 1D ---	8

**ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO. CA 9200185  
SA 58781**

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on  
The European Patent Office is in no way liable for those particulars which are merely given for the purpose of information. 20/07/92

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-0304728	01-03-89	JP-A- 1072542 US-A- 4910580	17-03-89 20-03-90
EP-A-0430403	05-06-91	JP-A- 3220751 US-A- 5070391	27-09-91 03-12-91
US-A-4999160	12-03-91	None	
US-A-4107726	15-08-78	US-A- 4164461	14-08-79

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This limit of solid solubility can be estimated by looking at various aluminum-titanium phase diagrams shown in figures 14a to 14g.

Table 4 summarizes published wt % Ti solubility limits at the eutectic temperature of 665.1°C, at the peritectic temperature of 660.4°C, at the TiN barrier limit temperature of 550°C, which is the highest temperature that TiN can see before aluminum penetration and attack, and at the metallization limit temperature of 500°C which is the highest temperature that the semiconductor device will see during and/or after aluminum metallization.

TABLE 4

	Sample No.	665.1°C	660.4°C	550°C	500°C
15	1	0.15	>1.00	?	?
	2	0.19	0.28	<0.20	<0.20
	3	0.05	0.29	0.16	0.14
	4	0.15	1.20	?	?
	5	0.15	1.18	0.37	0.20
20	6	0.15	0.32	?	?
	7	0.15	1.08	0.40	0.22
	8	0.15	1.08	0.40	0.22
	9	0.16	?	?	?
	10	0.15	1.00	?	?
25	11	?	1.25	?	?

This table shows that up to 0.19 wt % Ti can enter in solution in the aluminum alloy melt at the eutectic temperature of 665.1°C; that titanium supersaturated aluminum alloy solid solution containing up to about 1.25 wt % Ti can be obtained at the peritectic temperature of 660.4°C; and that up to about 0.40 wt % Ti can dissolve at 550°C and that up to about 0.22 wt % Ti can enter solid solution at 500°C.

The bulk resistivity of pure aluminum is 2.65  $\mu\Omega\cdot\text{cm}$  at room temperature. The bulk resistivity of aluminum-titanium alloys increases at a rate of 2.88

$\mu\Omega$ .cm per wt % Ti in solid solution and at a rate of 0.12  $\mu\Omega$ .cm per wt % Ti out of solution. It is then necessary to keep the titanium content of the aluminum alloy at a minimum to ensure the lowest possible bulk resistivity.

The most common aluminum alloy that is used as interconnect material of devices without a barrier layer contains (98.5 wt % Al) - (1.00 wt % Si) - (0.50 wt % Cu) and has a theoretical bulk resistivity as high as 3.84  $\mu\Omega$ .cm when all the silicon and copper is dissolved in aluminum. This represents 1.24 times the bulk resistivity of pure aluminum.

The aluminum alloy containing about 0.40 wt % Ti, which is needed to stabilize the (poor quality TiN)/(aluminum alloy) interface to a temperature of up to 550°C, has a theoretical bulk resistivity that can be as high as 3.80  $\mu\Omega$ .cm when all the titanium is dissolved in aluminum. This represents 1.43 times the bulk resistivity of pure aluminum.

In accordance with the invention, aluminum alloys used as the interconnect layer contain titanium in contact with TiN layers in devices exposed to temperatures lower than 550°C and preferably in the 450-500°C range. The titanium content may be as large as the limit of solid solubility at the peritectic temperature of 660.4°C, which is 1.25 wt %, but is preferably lower than 0.40 wt % and can be as small as 0.05 wt %.

The titanium containing aluminum alloy can be deposited as a sputtered film. It is also possible to deposit this alloy by co-evaporation of aluminum and titanium, by low pressure chemical vapour deposition, LPCVD, by metalorganic chemical vapour deposition,

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## Claims:

1. A semiconductor device characterized in that it comprises at least one metal interconnect layer, a metal compound based barrier layer in contact with said metal interconnect layer, and said metal interconnect layer containing said metal of said compound in an amount up to the limit of solid solubility at the peritectic temperature.
2. A semiconductor device as claimed in Claim 1, characterized in that said titanium-based barrier layer is titanium nitride.
3. A semiconductor device as claimed in Claim 1 or 2 characterized in that said metal interconnect layer is selected from the group consisting of:  
aluminum, gold, tungsten and copper.
4. A semiconductor device as claimed in Claim 2 or 3, characterized in that the titanium nitride in said barrier layer is a stoichiometric single-phase, face-centered  $\delta$ -TiN.
5. A semiconductor device as claimed in Claim 2 or 3, characterized in that the titanium nitride in the barrier layer is non-stoichiometric single phase face-centred cubic  $\delta$ -TiN.
6. A semiconductor device as claimed in Claim 2 or 3, characterized in that the titanium nitride in the spike suppression layer is tetragonal  $\epsilon$ -Ti<sub>2</sub>N.
7. A semiconductor device as claimed in Claim 2 or 3, characterized in that the titanium nitride in the barrier layer is a solid solution of two or more of the compounds selected from the group consisting of:

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stoichiometric single phase, face-centred cubic  $\delta$ -TiN;  
non stoichiometric single phase face-centred  $\delta$ -TiN; and  
tetragonal  $\epsilon$ -Ti<sub>2</sub>N.

8. A multilayer semiconductor device  
5 characterized in that it comprises first and second  
aluminum alloy interconnect layers, a titanium nitride  
barrier layer over said first aluminum alloy  
interconnect layer, and a dielectric layer over said  
barrier layer, said first aluminum alloy interconnect  
10 layer containing titanium in an amount between 0.05 wt  
% and the limit of solid solubility at the peritectic  
temperature.

9. A multilayer semiconductor device as claimed  
in Claim 8, characterized in that the amount of  
15 titanium on the first interconnect layer is less than  
0.4 wt %.

10. A multilayer semiconductor device as claimed  
in Claim 8 or 9, characterized in that titanium nitride  
in the barrier layer is stoichiometric single phase,  
20 face-centred cubic  $\delta$ -TiN.

11. A multilayer semiconductor device as claimed  
in Claim 8, characterized in that the barrier layer is  
a non-stoichiometric single-phase, face-centred  $\delta$ -TiN.

12. A multilayer semiconductor device as claimed  
25 in Claim 8, characterized in that the titanium nitride  
in the barrier layer is tetragonal  $\epsilon$ -Ti<sub>2</sub>N.

13. A multilayer semiconductor device as claimed  
in claim 8, characterized in that the titanium nitride  
in the barrier layer is a solid solution of two or more  
30 compounds selected from the group consisting of:  
stoichiometric single phase, face-centred cubic  $\delta$ -TiN,